Conceptualising global water challenges

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Conceptualising global water challenges: A transdisciplinary approach for understanding different discourses in sustainable development

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ABSTRACT

Global challenges impact upon substantial numbers of people in different locations and inform policy at multiple levels under the United Nation's Sustainable Development Goals (SDGs). An aspect of the SDGs framework is the stated inter-relationship between SDGs and local, regional and global partnerships for research and development. In response to dissatisfaction with existing approaches to addressing such complex problems the purpose of this paper is to propose a problem-language-context (PLC) model as a way of framing sustainable development challenges; and in so doing create a heuristic that allows challenges such as water security to be understood using a logically consistent framework. Such an approach builds on a growing transdisciplinary innovation literature that strives to generate knowledge that is problem-focused and inclusive of both scientific and societal stakeholders. The utility of the PLC model is then examined using a case study review carried out on a body of evidence - the United Nations World Water Development Reports (WWDRs) 2003–2019. The result of this review suggests that such problem framing can be of value in revealing the implicit (and sometimes contradictory) assumptions held by policy makers, practitioners and researchers. The main conclusion is that a transdisciplinary approach is one way of better understanding some of the conflicting viewpoints evident in discipline-based approaches to sustainable development, global water challenges and water security.

1. Introduction

In 2016 the United Nations declared the period from 2018 to 2028 to be the international decade for action relating to *Water for Sustainable Development*. The declaration highlighted both the lack of progress in achieving the Sustainable Development Goal of access to clean water (SDG 6) and emphasised the need for further steps to accelerate "… science, research and innovation for sustainable development …" (UNGA, 2016, p. 5). In a subsequent thirty-year review of water and the innovation literature, Wehn and Montalvo identified a striking absence of studies relating to water innovation: proposing *Water Innovation Studies* as an emerging and distinct field of problem solving and research, driven by "changing human needs within a complex and dynamic environmental setting" (Wehn and Montalvo, 2018, p. 3). Such proposals are arguably symptomatic of the emergence of a *sixth wave* of innovation that highlights a growing recognition of the social and inclusive aspects of innovation (Silva and Di Serio, 2016): encompassing concepts such as sustainability-led innovation (Seebode et al., 2012); and transdisciplinary innovation. The latter concept is the focus of our article, where the concept of transdisciplinary innovation can be characterised as "… action-oriented and future-focused, participatory, holistic, and systemic … transcending individual disciplines or practices." (Bliemel and van der Bijl-Brouwer, 2018, p. 3).

The policy and research contexts introduced above, as well as recommendations from the United Nations World Water Assessment Programme (WWAP) over a twenty-year period, highlight dissatisfaction and frustration with attempts to engage with such sustainable development challenges. In response to the above debate, the purpose of this paper is to suggest a heuristic that can be used by researchers and practitioners to understand the multiple perspectives evident in water

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security and the wider global water challenges. The model is based on the experiences of one network of scientific and societal partners tasked with addressing water challenges in different settings (www.safewater-research.com). Three questions guided our thinking:

i. Can transdisciplinary approaches be used to frame water sustainability challenges in a way that recognises multiple scientific and societal perspectives?
ii. Can such framing be used to evaluate a coherent body of evidence relating to the global water challenge in a way that explains the sources of dissatisfaction?
iii. How does such framing and evaluation contribute to an integration of approaches for addressing future water sustainability and security?

The remainder of the paper is structured as follows: firstly, the transdisciplinary literature is used to inform the construction of a conceptual model that attempts to represent the multiple perspectives evident in global water research. Secondly, we present the methodology used to undertake a review of the evidence – the United Nations World Water Development Reports (WWDRs) published during the period 2003–2019. Thirdly, we present the results of the review using our transdisciplinary conceptual model. Fourthly, we discuss key insights from the review with a particular focus on explaining different water discourses evident in our network of scientific and societal partners. Finally, in the conclusion, we suggest that transdisciplinary approaches are one way of understanding the apparent contradictions evident in water research discourses.

2. Conceptual model

The problem-language-context (PLC) model presented below is conceived as a multi-level approach for understanding sustainable development, including global water challenges. The issues outlined in the introduction suggest the need to recognise multiple perspectives for those who are addressing such challenges — both in terms of different geographical contexts and at different levels of analysis. For example, based on a review of ten water research projects, Krueger et al. (2016) highlighted the inherently partial and sometimes conflicting approaches to water research evident amongst different scientific and societal stakeholders, in particular the subordinate role of social sciences in such research. Such conclusions are indicative of the tensions and contradictions evident amongst different stakeholders who adopt multiple perspectives and have differing priorities.

As a way of better understanding the tensions and contradictions identified in water research, we examined the transdisciplinary research (TDR) literature to gain an understanding of how this approach might offer an alternative way of conceptualising sustainable development relating to water research and thereby be of practical value for understanding water access and security. Each of the components of the model are explained in the following subsections.

2.1. Problem representation

A starting point for TDR is engagement with a societal problem (Klein, 2014). This is contrasted with the approach taken in academic paradigms which typically start with gaps in discipline knowledge (Morgan, 1980). Indeed, an emerging literature can be identified that privileges *problematization* as a driver for innovation (Alvesson and Sandberg, 2011). The basis of problematization is the surfacing of assumptions that researchers have about a particular challenge or issue. Within TDR discourse, Max-Neef (2005) in particular, drew on research pioneers in an attempt to address the issue of how problems are represented. Problem representation was also addressed by Jantsch (1970) in his work on universities and innovation. What these writers appear to share is an approach to organising their ideas that uses the conceptual technique of *levels* in terms of problem solving. Max-Neef developed this idea and used layering to distinguish between different categories of questions used by researchers to investigate a particular problem area. Geels (2002) used a similar multilevel technique and emphasised that such levels are "… not ontological descriptions of reality, but analytical and heuristic concepts …" (Geels, 2002, p. 1259). Table 1 is presented as a stylized attempt to summarize such problem representation. Working from left to right the first column distinguishes between different categories of questioning. The second column identifies the types of discipline that tend to use each category of questioning. The third column presents a descriptor used to distinguish between the different levels — what Hirsch Hadorn (2008) calls problem identification and structuring. For the purposes of illustration, the fourth column provides an example of each category from the water research literature.

Table 1
Problem representation: understanding water challenges at different levels of analysis.

Question category	Discipline types	Problem descriptor	Water example
What we must do OR how to do what we want to do?	Ethics, philosophy, religion.	Values-based	Water human rights. (de Albuquerque, 2014)
What is it that we want to do?	Planning, politics, law, management.	Normative	Water Management. (Das, 2016)
What are we capable of doing?	Engineering, agriculture, industry, commerce.	Pragmatic	Water Infrastructure. (Crow-Miller et al., 2017)
What exists?	Physics, chemistry, geology, ecology, physiology, genetics, economics.	Empirical	Water Quality. (WHO, 2017)

(After Hirsch Hadorn, 2008; Jantsch, 1970; Max-Neef, 2005).

Distinguishing between different categories of problem representation is best understood by reading upwards from the bottom row to the top row in Table 1. The empirical level refers to what exists in the sense of attempts to describe the world as it appears to be: through the study of the principles governing; nature, life, and societies. Within water studies the empirical level can be considered to include issues such as pollution and water quality. The pragmatic level refers to what we are capable of doing and relates mainly to the technological disciplines; for example, the spatial considerations of water infrastructure. The normative level refers to what societies want to do: this category of question is concerned with how societies make decisions relating to how they want to influence, design, or manage their affairs. Within water studies the normative level can be considered to include issues relating to the management of water resources. The values-based level refers to what we must do and can be considered the category of problem solving relating to ethics, philosophy, and religion; for example, issues relating to the human right to water. By using this approach, different categories of question can be used to represent a particular problem at different analytical levels. This forms the first axis of our PLC model and allows different kinds of water challenge to be represented in a meaningful structure.

2.2. Language organisation

TDR as problem solving is one of what Osborne suggests are closely related but "distinct intellectual profiles" (Osborne, 2015, p. 9). (i.e., an innovation systems approach; a science-policy approach; and a research methodology approach). Each intellectual profile has an associated discourse or language that has evolved and is used in that tradition. Indeed, Klein (2008) suggested that a key reason for the evolution of TDR as an approach to problem solving was in relation to global, North-South partnerships for sustainability and the need for the inclusion of a wide range of stakeholders when addressing complex problems.

Table 2
Language organisation: recognizing different social discourses in water research.

Meaning category	Discourse form	Language organisation	Water example
Understanding human survival in a changing environment.	Standardized ways of engaging with a certain phenomenon.	Sustainability	Ecohydrology (Falkenmark and Rickström, 2004).
Constructing frameworks and systems.	Assembly of discourses in an integrated frame.	Planning	Integrated water resource management (IWRM) (GWP, 2000).
Generalizing patterns in particular contexts.	Control, self-renewal, communication, and direction.	Control	Inter-basin water transfers (Gupta and Van der Zaag, 2008).
Describing the world as it is.	Logical interpretation in a specific context.	Logic	Access to water (Aleixo et al., 2019).

(After Alvesson and Karreman, 2000; Alvesson and Kä;rreman, 2011; Jantsch, 1970; Max-Neef, 2005).

In a similar vein, Alvesson and Karreman (2000) examined the importance of language in social sciences as *discourse*: distinguishing between discourse as talk and written text; and discourse as the shaping of social reality through language.

The idea of the importance of language and discourse derives in part from an intellectual tradition that highlights the implicit role of language in attempting to explain the domain of the human sciences and the significance of meaning (Foucault, 1966). Based on these insights we present Table 2 as an attempt to summarize language organisation as follows: working from left to right the first column identifies different categories of meaning. The second column identifies the forms of discourse that tend to be used with each meaning category. The third column presents a descriptor used to describe the different levels. The fourth column provides an example of each category of language organisation found in water research.

The logic level refers to an organising language based on observation and interpretation, while the control level refers to an organising language that is based on cybernetics or a controlling view of the properties of nature and society. The planning level refers to the management and perception of water as a resource. The sustainability level refers to how humanity is capable of surviving in a dynamically changing world (Max-Neef, 2005). This forms the second axis of the PLC model and allows types of water discourses to be understood as taking place within a particular organising language. Both problem representation (the first axis of the model) and language organisation (the second axis of the model) take place within a particular setting or context which is addressed in the following subsection.

2.3. Contextual setting

In considering *contextual setting*, we drew on two traditions that are orientated towards application and practice — consistent with the emphasis on practical problem solving in TDR. The first tradition is *appreciative theorising* (Nelson and Winter 1982); what Nelson describes as "theory that aims to capture the basics of what is actually going on" (Nelson, 2007, p. 1). We use a multi-level perspective (Rip and Kemp, 1998) that aims to integrate findings from different literatures as a nested hierarchy of concepts: reflecting the complexities of real-world problems. Developing this approach and in an exploration of environmental innovation and change, Geels (2011) made a multi-level distinction between: niche innovations; patchworks of sociotechnical regimes; and evolving sociotechnical landscapes relating to environmental problems.

The second tradition informing our thinking was *service dominant logic* (SDL) which has emerged from the marketing literature as a re-evaluation of the concept of *value* (Vargo and Lusch, 2004). It can be contrasted with product dominant logic and emphasises the idea of value as co-creation (as opposed to value as exchange) between partners in any transaction or engagement. Recent theoretical development of SDL has highlighted the philosophical linkages between SDL and a transdisciplinary approach to research based on an emphasis on value co-creation between different scientific and societal partners (Lusch et al., 2016; Vargo and Lusch, 2017). One insight from the theoretical development of SDL is the idea of aggregation levels (Chandler and Vargo, 2011) as a way of distinguishing different types of engagement. In Table 3 we conceptualise place and location as *contextual setting*: working from left to right the first column distinguishes between different spatial settings or focus. The second column identifies the form of aggregation used in each setting. The third column identifies a descriptor used to distinguish between the different levels of context – what Geels (2002) calls a nested hierarchy. The fourth column provides an example of each context evident in water research.

The niche level refers to a context in which learning takes place through doing, using, and interacting, as well as providing the social networks that support innovation (Lundvall, 1992; Von Hippel, 1988). The regime level refers to a context that exemplifies the established ways of doing things – especially with regards the use of a particular technology (Nelson and Winter 1982). This is associated with technological

Table 3
Contextual setting: the significance of place and time for water challenges.

Focus	Aggregation form	Context level	Water example
Evolving landscapes.	Meta.	Ecosystem	Water ecosystem nexus (Coates and Smith, 2012).
Sociotechnical landscapes.	Macro-national, global, local.	Landscape	Virtual water (Hoekstra and Hung, 2002).
Sociotechnical regimes.	Meso regime - technological, science, policy, socio-cultural, users and markets.	Regime	Water metering (Cairns, 2018).
Individuals, teams, and community niches.	Micro-engagement, transactions, sharing, social networks, learning.	Niche	Water containers (Patwardhan, 2017).

(After Chandler and Vargo, 2011; Geels, 2002, 2004; Vargo and Lusch, 2017).

trajectories that guide the direction of incremental innovation. The landscape level refers to the socio-technical context within which multiple regimes are situated – including political, economic, and environmental factors (Geels, 2002; Kemp et al., 2001). The ecosystem level refers to a context into which time and replication are introduced (Chandler and Vargo, 2011; Giddens, 1979).

2.4. Transdisciplinary knowledge

A final contribution to our model building was by relating the proposed PLC model to the three types of knowledge commonly used in TDR: *systems knowledge*; *target knowledge*; and *transformation knowledge* (Brennan and Rondón-Sulbarán, 2019; Hirsch Hadorn et al., 2008; Hoffman et al., 2017; ProClim, 1997; Wiesmann et al., 2014). The basic distinction between the types of knowledge is that systems knowledge relates to the current status of a problem; target knowledge relates to a desired future status; and transformation knowledge relates to how to make the transition from the current status to the desired future. The proposed PLC model can incorporate the transdisciplinary knowledge typology as follows: Systems knowledge relates to a contextual setting which is framed through a particular way of representing the nature of the problem and the language used. Target knowledge relates to how a problem is represented as framed by language and a particular contextual setting. Transformation knowledge relates to language organisation as framed through a particular context and the manner in which a problem is represented. Fig. 1 is a visual representation of the PLC model and incorporates the three types of transdisciplinary knowledge.

In summary, we propose that the ideas presented in Fig. 1 can be used as a framing device for researchers and practitioners addressing sustainable development challenges — and water access and security issues in particular. Further, we suggest that such framing will help unpack the multiple perspectives typically adopted by different stakeholders. Finally, we contend that such problem structuring can be used as a frame of reference for understanding the reported contradictions in water research (Krueger et al., 2016).

3. Methods

The PLC model presented above, emphasises the importance of framing with regards to perceptions of sustainable development challenges such as water access and security. The need for such framing is highlighted by previous reviewers of United Nations World Water Development Reports (WWDRs), considered the authoritative international discourse on global water challenges. For example, Swyngedouw (2013) in a review of the 2012 *Managing Water Under Uncertainty and Risk* report; and Shah et al. (2018) in a review of the 2016 *Water and Jobs* report, highlighted the multiple perspectives adopted and the contested nature of water-related knowledge. Given such assessment, we identified these WWDRs as a body of relevant literature that offered extensive coverage of water-related issues encompassing the complexity of use and management of freshwater resources around the world. Thus, ten of the WWDRs published between 2003 and 2019 became the data sources of our case study. In order to manage the analysis of large amounts of qualitative data, we identified the meta-ethnography methodology as a suitable approach for synthesizing qualitative studies (Noblit and Hare, 1988).

This methodology enables the synthesis of multiple qualitative research studies with a view to producing new interpretations. Crucially, given the nature of water research, the approach "goes beyond the findings of individual studies synthesised and does not simply aggregate findings" (France et al., 2019, p. 2). As originally conceived, the approach consists of seven iterative and overlapping phases (Noblit and Hare, 1988). The description of each phase of the research activity undertaken is presented in Table 4. Whilst Table 5 presents the WWDRs organised chronologically in ascending order (from 2003 until 2019) and summarised within a framework under the following headings: title/year, focus, description, key issues, and interpretive comments.

Considering the vast amount of data (the length of the reports varied between 909 and 154 pages) and guided by the description of the reports initially prepared and shown in Table 5, we decided to approach the data extraction using word frequencies and visual word clouds that could reveal patterns, similarities, and differences in a *quasi*-content

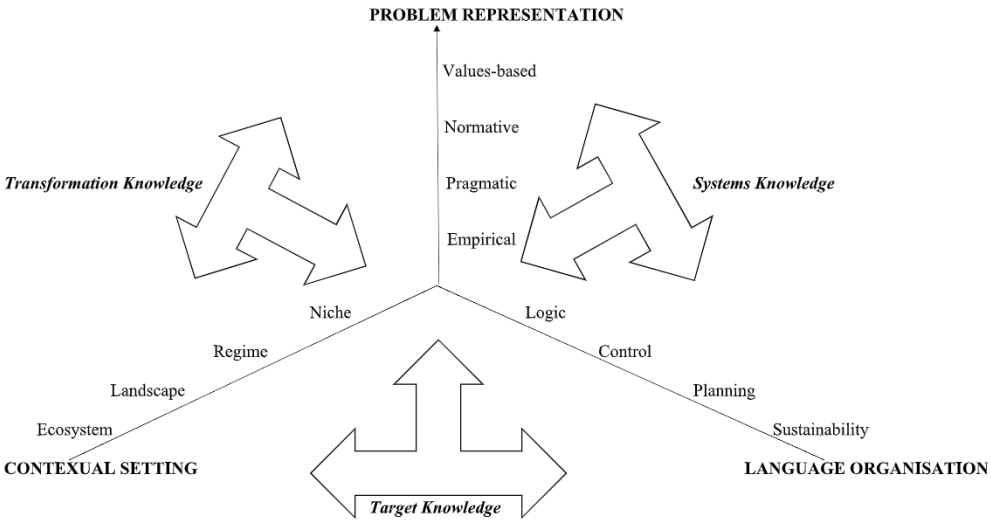

Fig. 1. A Problem-Language-Context (PLC) model for understanding water research.

Table 4
Meta-ethnographic analysis.

Phase	Description	Research activity
1.Starting	Deciding the focus of the synthesis.	UN Sustainable Development Goals and SDG6 – Water.
2. Selecting	Identifying and selecting relevant accounts to synthesize.	Purposeful selection of UN World Water Development Reports 2003–2019 (n = 10) as the authoritative international discourse on the world's freshwater.
3. Interpreting	Reading of accounts and noting interpretations.	Listing and documenting what the accounts are about through: focus, description, key issues, and initial interpretative comments.
4. Relating	Determining in what ways the accounts are related.	Qualitative analysis using NVivo. Juxtaposing across studies and relating studies by grouping common concepts through thematic analysis.
5. Translating	Translating the accounts into one another by interpreting meaning through reciprocal translation and refutational translation.	Identification of the: focus, theories, concepts, themes, metaphors, paradigms, and how innovation is addressed in the accounts. Interpretation using both reciprocal translation (i.e., the assuming that studies can be added together) and refutational translation (i.e., identifying contradictory themes, concepts or findings).
6. Synthesizing	Making a whole that is more than the individual accounts.	Discussing the results as: • Reciprocal accounts • Refutational accounts • Dissimilar but related accounts
7.Communicating	Communicating the synthesis.	Discussion of the results in terms of the PLC model.

(After Campbell et al., 2011; France et al., 2019; Noblit and Hare, 1998).

analysis. Thus, the documents were uploaded to NVivo 12 to be able to run word frequency queries and create word clouds of each of the documents to allow such visualisation of the data. The most frequent 1000 words of the word frequency and the 20 more prominent words of the word cloud from each report were exported into Excel files for analysis with the purpose of revealing the presence of similarities, dissonances or meaningful relationships of certain themes, concepts, or categories.

4. Findings/results

In relation to the problem representation according to the PLC model, the results of the interpretation of the reports as a body of evidence suggests that early WWDR reports were concerned with the description and identification of water problems. Further, that the dominance of an economics-based view of development was beginning to be questioned, and new ways of understanding water challenges highlighted. The need for governance and engagement with stakeholders at different levels was consistently reported, as was the need to adopt a more holistic approach to water studies rather than a narrow sectoral approach. The multiple connections between water, economic development, social wellbeing, and environmental sustainability, were increasingly evident over the twenty-year publishing period — and the recognition of a need for new frameworks emphasised. The paradigms of sustainable development; the greening of economies; and new development goals were all introduced: leading to the interdependence of water with the new UN Sustainable Development Goals introduced in 2015 – as well as the articulation of a dedicated SDG6 for water. There was increasing evidence of a realization for the need to improve water infrastructure, storage, and management: and a recognition of opportunities through recycling in a *circular economy*. The significance of water within the sustainable development goals was further highlighted in more recent reports: nature-based solutions for water challenges (WWAP, 2018) and the human right to safe drinking water in order to eradication of poverty and creation of peaceful societies (WWAP, 2019).

However, largely unquestioned and implicit assumption across all WWAP reports concerns *change* i.e., that efforts to address the global water challenge are based on the teleological notion of striving towards a goal. The dominant concept that follows from such a teleological view is the notion of Integrated Water Resource Management (IWRM). This management paradigm is reflected in the metaphorical basis for the *Water in a Changing World* report, characterized as 'the water box' (WWAP, 2009, p. 4). The notion is based on attempts to think outside dominant paradigms in problem solving – a form of lateral thinking (de Bono, 1970). The box metaphor is used to characterise the water sector as bounded and that solutions to the water challenge needed to include wider society. Evidence from the reports suggests that over time, this dominant way of thinking has begun to be questioned. For example, the *Managing Water under Uncertainty and Risk* report (WWAP, 2012) discusses a shift in thinking from 'taming' or 'controlling' water, to 'trade-offs' (p. 136). Likewise, the *Water for a Sustainable World* report (WWAP, 2015) suggested a need to shift from 'goals to managed trade-offs' (p. 59) reflecting a change in thinking about the actual process of change. The outworking of this shift in thinking was reflected in a move away from *predict and control* to *capacity building*. More recently, the 'mother earth or mother nature' paradigm (WWAP, 2019, p. 23) was introduced. The notion of water as an economic resource (WWAP, 2016 *Water and Jobs*, and WWAP, 2017 *Wastewater*), whilst recognized as the dominant way of thinking about water, was increasingly challenged. For example, the *Water in a Changing World* report suggested that thinking about water as *natural capital* was 'particularly misleading' (WWAP, 2009, p.14). The *Managing Water under Uncertainty and Risk* report (WWAP, 2012) further emphasised the need to adopt alternative perspectives in addition to the dominant resource view.

In the earlier reports, economics-based theories and concepts explicitly underpinned thinking about the water challenge. Such thinking addressed the issue of different and 'normative' ways of valuing

Table 5
World water development reports analysis.

The United Nations World Water Development Reports				
Title/Year	Focus	Description	Key issues	Interpretive Comments
Water for People, Water for Life, 2003.	Water problems.	A comprehensive view of today's water problems. Eleven key water-related issues are discussed.	Water quality, water management (integrated, wastewater), water governance, water and energy, pollution (the environment and ecosystems), water-related diseases, sustainability.	The report highlights the key role of governance to support the development of sustainable solutions and the importance to of valuing water beyond its economic value – the social, cultural, religious, and environmental value of water need to be recognized.
Water: A Shared Responsibility, 2006.	Water and the achievement of the MDGs.	An overview of the effect of major changes in the world on freshwater resources worldwide and how these challenges impact on the progress towards the achievement of the UN Millennium Development Goals (MDGs).	Integrated water resource management, governance, demographic changes, and geographic distribution of populations, changing ecosystems, food production, health, industry, and energy; risk management.	The increasing and rapid changes in the world highlight the need to have a focus on water governance and to engage all stakeholders at all levels of society in the sustainable use, productivity, and management of the increasingly diminished freshwater resources.
Water in a Changing World, 2009.	A holistic approach to water problems.	In the face of the rising problem of water scarcity around the world and the recognition to improve the sustainable use of water, this report highlights the need for a holistic approach in relation to what has traditionally been considered the 'water sector.'	The report has a focus on four key thematic areas covering issues related to climate change, the MDGs, groundwater, biodiversity, infrastructure, migration, biofuels, ecosystems.	The findings in the report demonstrate how decisions impacting on water management and use are influenced by numerous external factors. The report underscores the need for public investments in water resources infrastructure and implementation capacity and emphasises the link between water resources and environmental sustainability.
Managing Water Under Uncertainty and Risk, 2012.	Water issues looked at from the perspective of uncertainty and risk.	In this report, water is examined in terms of water demand and its link to energy crisis, industry, and human activities. This document underscores the central role of water in all aspects of economic development and social welfare, and the need for integrated and collective approaches involving all water-using sectors to guarantee that everyone capitalizes equally on water's multiple benefits.	Major changes, uncertainties and risks surrounding water resources; water supplies, uses and management; institutions, sectors and financing; gender equality, water-related disasters, health, ecosystems.	The need to develop new frameworks considering the multiple interlinkages of the development nexus, together with the different risks, uncertainties and costs and benefits. All stakeholders need to participate in decision-making processes.
Water and Energy, 2014.	The water-energy nexus.	The report focuses on the complex interlinkages of water and energy and how actions taken in one domain positively or negatively impact the other. The report also marks the movement towards a new paradigm of sustainable development shaped by the new development goals and the advent of the 'greening' of economies.	Energy and freshwater demands, water tariffs, private sector, research and development, industry, water and energy governance, sustainable industrial development.	The report calls for policy makers, planners, and practitioners to face the challenges in their respective domains and develop innovative national policies aimed at an appropriate provision of water and energy services in an integrated way.
Water for a Sustainable World, 2015.	Interdependency of water and global sustainability.	Under the premise that 'water is at the core of sustainable development', the report demonstrates how water is vital for most sustainable development endeavours and how a dedicated SDG for water would contribute to sustainable development in all domains.	Natural water cycle, sustainable development, water resource management, water services, novel approaches, ecosystems, ecosystems services, built and natural infrastructure, joint decision making.	The document outlines the need of extending the focus on water beyond drinking water and sanitation to the global management of the water cycle. Recognizing water as the fundamental resource that underpins all forms of sustainable development requires an innovative and novel approach to management.
Water and Jobs, 2016.	Centrality of water for jobs and sustainable development.	The interdependency between water and the creation of job opportunities, either directly linked to its management or in the water-dependent economic sectors is highlighted in this edition. The report also demonstrates how access to drinking water and sanitation are key to a healthy and educated workforce who can support a sustainable economic growth and also underscores the importance of water in the transition to a green economy.	Water scarcity, water-dependent sectors, economic growth, and employment, developing countries, public-private partnerships (PPPs), (green) technological innovation, market competition.	The report highlights the need for investments in water-related infrastructure, storage and management and it calls for the development of innovative technologies to improve water use and productivity and market competition to increase jobs at a global level in all sectors – not only in the water sector.
Wastewater: The Untapped Resource, 2017.	Managing wastewater for sustainable development.	In this edition, the key role of wastewater is highlighted in the context of its contribution to a circular economy. The report highlights the importance of viewing wastewater as a valuable and sustainable source of water, energy, nutrients and numerous	Wastewater management, (un)treated wastewater, environmental sustainability, natural resources, sustainable economy, water quality.	Awareness raising to overcome negative perceptions of wastewater and ensure wide public participation in reuse schemes is recommended. A need for a change of paradigm: shifting from 'treatment and disposal' to the '4 Rs: reduce (pollution), remove

(*continued on next page*)

Table 5 (*continued*)

The United Nations World Water Development Reports				
Title/Year	Focus	Description	Key issues	Interpretive Comments
		recoverable by-products, rather than a problem.		(contaminants), reuse (treated water) and recover (useful by-products).
Nature-based Solutions for Water, 2018.	Exploring nature's potential in achieving sustainable water solutions.	The report explores the potential of nature-based solutions (NBS) to address water management challenges stressing the need for a balance between the existing grey infrastructures and the under-utilized green infrastructures that could aid sustainable economic growth while supporting the regeneration of the ecosystems and biodiversity.	Solutions mimicking nature, change the 'business-as-usual' approaches, green and circular economy, protection of sources, innovative solutions based on nature, grey/green infrastructure, risks reduction.	NBS can be highly effective in improving water quality and supply, and increasing ecosystems restoration. There is a need to increase awareness and knowledge of NBS at all levels and foster cross- sectoral collaboration.
Leaving No-one Behind, 2019.	The human right to safe drinking water and sanitation as the basis towards sustainable development.	This edition of the report emphasises the need to improve water resources management and access to water supply and sanitation services in order to eradicate poverty and tackle socio-economic inequities to create the path for sustainable development.	Human rights, socio-economic development, access to water supply and sanitation, water resources management, socio-economic inequities, sustainable development.	The report is a reminder that the adoption of the 2030 Agenda for Sustainable Development and the recognition of the human rights to safe drinking water and sanitation, are fundamental for the eradication of poverty. This forms the basis of peaceful societies.

water (WWAP, 2003, p.333). The notion of various forms of capital was highlighted and the need to move beyond economic ideas; to embrace social and cultural approaches was identified. The *Managing Water under Uncertainty and Risk* report again emphasised the need to move beyond the notion of water as a 'sector' (WWAP, 2012, p.20) and water as a 'resource' (p.292) in addition to the disputed concept of water scarcity. Integrated water resource management (IWRM) was reported as gaining popularity among WWAP case study partners whilst emphasising the need to include a wider range of stakeholders. The dominance of the IWRM approach continued in the reports — though was increasingly questioned. For example, natured-based approaches were reported as not being well integrated into IWRM (WWAP, 2018). New concepts such as: *virtual water* (WWAP, 2006); *water footprint* (WWAP, 2009); *Watergy* (WWAP, 2014); the *Green Economy* and *Ecohydrology* (WWAP, 2018); were all introduced – reflecting repeated attempts to conceptualise water in new ways.

Overall, the dominant theme evident throughout the reports is the concept of IWRM. This concept has implicit assumptions relating to water as an economic resource, and an engineering approach to the management of water. However, the results of our *translation* exercise suggest that both sets of assumptions are being challenged. For example, the limitations of the IWRM concept are increasingly evident in later reports. While the scope of management has expanded from an engineering-based view to a resource-based view; and more recently, to a more holistic, systems perspective with an emphasis on capacity building in different settings. The need for constant innovation is a repeated message throughout the reports — although the meaning and scope of innovation has expanded. Whilst innovation as technological interventions and engineering solutions was highlighted in the earlier reports, the need for understanding innovation in different ways is increasingly evident. Capacity building, knowledge management and dissemination were increasingly evident in later reports.

In summary, our analysis revealed that the ten reports can be divided into two distinct groups: the first group (2003–2012) can be characterised as an attempt to present the scope of the global water challenge: in other words, an emphasis on *problem representation* of our PLC model. The importance of sustainable solutions and ways of valuing water beyond economic value were introduced. The concept of IWRM was highlighted as a conceptual framework within which sustainable solutions could be developed. The *Water: A Shared Responsibility* report (WWAP, 2006) contextualised the global water challenge within the UN Millennium Development Goals – the precursor to the Sustainable Development Goals (2015–2030) and emphasised the need to engage with multiple stakeholders. This view was developed in much more detail in the *Water in a Changing World* report (WWAP, 2009). In particular, the need for holistic solutions was highlighted as well as the need for such solutions to be considered outside the traditional notion of a water sector. The *Managing Water under Uncertainty and Risk* report (WWAP, 2012) marked a dramatic shift in emphasis. This substantial work embraced a wide-ranging re-evaluation of the water challenge and in particular linked this to all aspects of economic development and wider human activities. The need for new frameworks and approaches to water was emphasised together with a questioning of a narrow, sector-based understanding of water challenges.

The second group of reports (2014–2019) reflected a change to annual editions based on a specific theme and combined with examples of practice from different geographical locations. This shift in thinking reflects much more emphasis on language organisation and different discourses, as well as a recognition of the significance of different geographical contexts. Whilst primarily examining water and particular economic themes (e.g., energy, employment, and wastewater), a noticeable departure was the examination of water holistically in terms of sustainable development (WWAP, 2015). In particular, the need for global approaches to the management of water was emphasised: and in addition, the inter-relatedness of developed and developing parts of the world in terms of water challenges. A recognition of the need for an approach to water innovation that encompassed more than technology (for example, governance, finance, and capacity building) was also highlighted. This recognition of the need to broaden the scope of water research and use alternative perspectives was further emphasised in the two subsequent reports: the *Nature-Based Solutions for Water* (WWAP, 2018) report is focused on exploring natural solutions through green infrastructure, rather than using grey infrastructure at a large scale (e.g., reintroduction of beaver dams in streams rather than building dams in large rivers); while the *Leaving No One Behind* (WWAP, 2019) report is focused on the human rights to water. The former introduced a significantly different set of assumptions about the ways in which societies could or should engage with water challenges. It further highlighted how historically developed, nature-based, solutions were not well represented in the dominant IWRM approach in water research. This change in emphasis was further evidenced by the 2019 report which highlighted the importance of a human rights-based approach to water and sanitation, in the context of socio-economic inequities. Taken together, these results suggest that there needs to be a consideration of the contextual setting in which solutions are to be applied. For example, natural solutions may take place at different levels of aggregation,

therefore, what works at meta, or macro level may not be suitable at micro level, where tailor-made solutions may be more appropriate.

5. Discussion

New ways of addressing water security and the global water crisis have recently been conceptualised within a framework consisting of types of innovation; stages of innovation; analysis levels; and innovation measurement, evaluation, and impact assessment (Wehn and Montalvo, 2018). This framework is based on a well-established way of understanding the water challenge from a resource-based view consisting of water resources management; water infrastructure; and water services. However, our analysis and interpretation of the United Nations WWDRs using a new PLC model designed in this study, suggests that alternative approaches to the global water challenge are increasingly evident. The dominant paradigm for global water studies is the concept of Integrated Water Resource Management, defined as:

> "… a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystem."
>
> (GWP, 2000, p.22)

Despite this dominance, perceived limitations of the paradigm have been repeatedly highlighted. For example: in terms of practical application (Biswas, 2004); the limited degree of research focus (Gallego-Ayala, 2013); and more recently, the lack of natured-based solutions to water challenges (WWAP, 2018). The result of our review supports the assertion that there is not a single unified body of knowledge relating to water studies (Swyngedouw, 2013). Further, that the universality of water knowledge is contested (Shah, 2018). This arguably highlights the need for models that can accommodate conflicting knowledge claims, in addition to the established discipline approaches to water knowledge creation.

We propose that the PLC model introduced in section 2, is one way of framing such novel approaches to water studies. Following the logic of the PLC model, an alternative framework for water innovation studies can be proposed that is based on the idea that innovation takes place within a particular *domain* of understanding. Such a domain can be envisioned as connecting each dimensional axis on Fig. 1 as a plane of "mutual dependences" (see Hirsch Hadorn et al., 2008, p. 31). Innovation involving both scientific and societal partners takes place within these overlapping domains and is based on particular problem, language and contextual combinations. This notion of overlapping domains, we suggest, begins to explain the contested and contradictory nature of much of water knowledge. In order to demonstrate how water challenges can be represented we present two stylized water domains (function-based and human rights-based) in Fig. 2 – based on our experiences of addressing water challenges through the SAFEWATER project.

The SAFEWATER project is a transdisciplinary research centre led by a university in the UK in partnership with academics, NGOs and key stakeholders in Brazil, Colombia, and Mexico. The aim of the project is the development of low-cost technologies for clean drinking water. Teams of engineers, academics, scientists, and community representatives from the different partner countries have come together to produce prototypes of water technology, first tested in the laboratories and then deployed in the target communities. In this function-based approach, the problem was analysed in a very pragmatic way, bringing together ideas for a technological solution that was dominated by the language of science and logic with the goal of disseminating a product, possibly at a large scale (e.g., water quality devices are being 'translated' into the market). Whereas, framing the problem using a rights-based approach, as suggested by social scientists involve in the project, may produce different results. This implies, analysing the problem not only in the laboratory, but in the field, through discussion and dialogue together with prospective end-users. Through these exchanges, using the language of sustainability and respecting different perspectives, as well as considering aspects that end-users deem important in their relationship with water and potential solutions; it is more likely that solutions to such problems as access to safe drinking water can be introduced and sustained.

The first domain, the function-based approach to water innovation studies involves: a pragmatic problem representation; a language of control; and a water regime in a specific contextual setting. The second domain, the human rights-based approach involves: a values-based problem representation; the language of sustainability; and a particular niche geographical setting. The contrasting domains illustrated in Fig. 2 differ in terms of what is privileged and considered of value. For example, the function-based approach emphasises technical efficiency, planning, infrastructure, and the role of producers and consumers within particular markets. This contrasts with the collective interest, regulation and fundamental rights in a particular geographical and social setting represented by a human rights-based approach. Such differences, we suggest, begin to explain the frustrations evident in water research and the need to recognise that any evaluation of water security depends on an understanding of different knowledge domains. Further, that new research directions in water innovation studies should include explicit *domain spanning* activities that recognise the necessary trade-offs

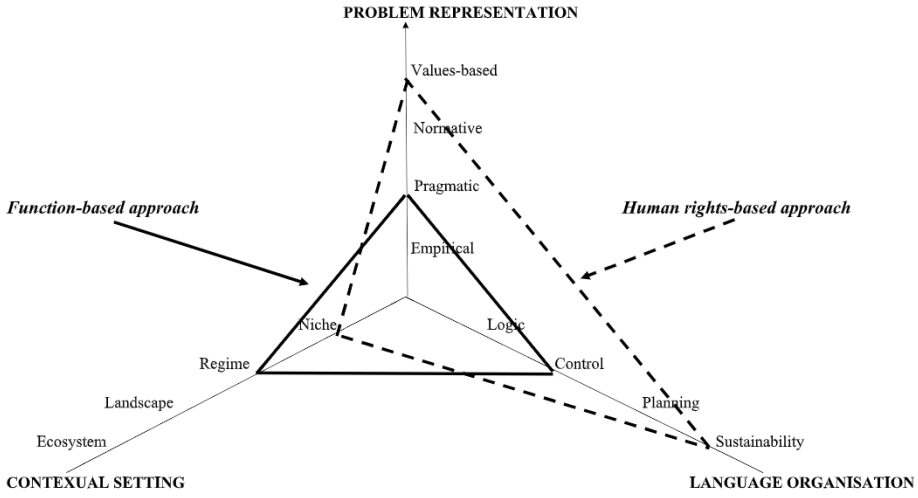

Fig. 2. Understanding water research as overlapping knowledge domains.

between different discipline approaches within an overarching transdisciplinary framework.

6. Conclusions

The stated purpose of this paper was to propose a heuristic that could be used by researchers and practitioners as a way of understanding the multiple (and often conflicting) perspectives evident in water innovation studies. Transdisciplinary approaches to addressing *real world* problems were used to construct the PLC model involving an understanding of how problems can be structured; the language used to articulate such problems; and finally, the contextual setting within which problems are located. We then reviewed a coherent body of evidence to identify dominant paradigms and contradictions. Finally, we explored how the PLC model could be used to explain different water discourses evident in our network of scientific and societal partners. This allowed a mapping of different perspectives and in so doing created a visualisation of how contrasting knowledge domains or paradigms 'cut across' each other. Such water domains can be considered social constructs, with the value of innovation determined based on such constructs. Using the PLC model suggests that water innovation studies can be considered as a series of overlapping domains that conceive innovation in different ways. The conclusion of our study is that a transdisciplinary approach is one way of overcoming the reported dissatisfaction of researchers and practitioners who are addressing water access and security. We suggest that such transdisciplinary innovation, in addition to discipline-based approaches, can enable researchers and practitioners to frame water challenges in a way that can provide additional insights in the pursuit of sustainable development goals.

Credit author statement

Michael Brennan: Conceptualization, Data curation, Writing – original draft preparation, Janeet Rondón-Sulbarán: Methodology, Data curation, Writing – original draft preparation, Lyda Patricia Sabogal-Paz: Writing – Reviewing and Editing, Pilar Fernandez-Ibañez: Writing – Reviewing and Editing, Ane Galdos-Balzategui: Writing – Reviewing and Editing

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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